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Building a wave energy policy focusing on innovation, manufacturing and deployment

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ABSTRACT

The Irish Government has set a goal to make Ireland a world leader for research, development and deployment of ocean energy technologies. Ireland has a wave energy resource of 21 TWh and an ambition is to achieve at least 500 MW installed generating capacity from ocean energy by 2020. This paper investigates what is required to move from ambition to delivery. A successful wave energy strategy will require focused policies that will stimulate *innovation* to develop the technologies, *manufacturing* to produce the devices and *deployment* to build the required wave power plants. The paper draws on the successful policies in Ireland that have stimulated each of these dimensions, albeit for different sectors. From 2004 to 2008, successful policies in (ICT and biotech) innovation led to an increase in Ireland's Innovation Index score from 0.48 to 0.53. The policy focus on (food and pharmaceuticals) manufacturing in Ireland resulted in high levels of economic growth over the period 1998–2002, reaching >10% GDP growth levels per annum, and full employment. Successful wind energy policies deployment has accelerated rapidly since 2003 and reached 1.2 GW installed capacity in 2009 representing 15% of Ireland's total installed capacity. The paper draws on appropriate elements of these policies to build a successful wave energy policy for Ireland. It also draws on the successful policies adopted in Denmark for innovation, manufacturing and deployment of wind energy. The Danish wind turbine manufacturers hold a world market share of approximately 40%. The paper proposes establishing a wave energy strategy group to develop an action plan to deliver the 500 MW. It also proposes a novel extension of corporate tax specifically for wave energy companies, an initial 30% capital grant scheme for wave energy developers, a grid code for wave energy devices and fast tracking of planning decisions through an amended approach to strategic infrastructure.

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1. Introduction

Wave energy is at a critical juncture in its development as a renewable energy technology. A demonstration power plant in Mutriku, Spain is in place with capacity of up to 300 kW [1] and commercial testing of Pelamis devices commenced during 2008 [2,3]. In addition, a number of countries have ambitious targets and policies in place with the goal of accelerating development and deployment and reaping the associated benefits [4]. The International Energy Agency (IEA) concludes however, in the Energy Technology Perspectives Report [5] that 'it is unlikely that the technology will play an important role before 2030'. It points to the need to scale up in order to withstand offshore conditions and high commercial risk. The development of appropriate wave energy policies and effective measures is essential to accelerate the development and deployment of wave energy technology and to address the barriers identified by the IEA.

A limited number of papers [6,7] draw on the successful development of wind energy in Denmark when discussing both the potential benefits associated with wave energy development and the stimuli required to develop a wave energy industry harness the compare the potential associated with wave energy. Wave energy policy papers [4,8–10] tend to be structured on the basis of R&D development for technology development and market support for pre-commercial deployment. This paper takes a different approach. It identifies three policy goals at the outset that are necessary for wave energy technology to become a commercial reality, namely innovation, manufacturing and deployment. Increasing innovative output is an important mechanism for approaching industrial and broader economic development issues [11]. Continuing improvements in national innovative capacity are intimately linked to sustainable growth in output and employment [12] and is required to scale up the wave energy technologies and to reduce costs. When mature, the manufacturing of wave energy devices for a European and global market offers significant potential economic benefits. Deployment is the final critical step required to penetrate the electricity market, to ensure wave energy contributes to meeting renewable energy and emissions reduction targets. While these three form a natural continuum for the development of a technology, they typically fall within the remit of separate Government Departments with their own priorities, mechanisms and success metrics. This paper reviews the success of policies associated with each of these goals in non-energy sectors and then seeks to establish how these may be applied to successful wave energy development.

Innovation policy falls under the remit of Departments responsible for science and engineering research with the goal of increasing the innovation capability within an economy and moving the economy further up the value chain. The key metrics of manufacturing policy is generally the responsibility of Departments responsible for industrial development, enterprise and employment with policies targeting job and wealth generation to increase economic output and value added.

Deployment policies fall under the remit of departments responsible for energy and environment, where the focus is on delivering targets relating to energy efficiency, renewable energy and emissions reduction.

The paper uses Ireland as a case study due to the size of its resource (up to 21 TWh[1] per annum accessible resource according to ESBI [13] and the extent of ambition behind the stated Government intent to 'make Ireland a world leader for research, development and deployment of ocean energy technologies [14]. This paper does not argue the merits of building a wave energy industry in Ireland that delivers all three elements. It does however seek to demonstrate what policy elements are necessary if the Government ambition is to be delivered.

Section 2 outlines the current status of wave energy policy in Ireland and compares it with the status in other countries. It structures the discussion according to the three policy goals, namely innovation, manufacturing and deployment. This allows the authors to identify gaps in the delivery of the three policy goals within Ireland.

Section 3 reviews what policies and measures have been employed in other sectors within Ireland to deliver goals associated with innovation, manufacturing and deployment. In the case of innovation policy, Ireland has established a clear goal for the economy to move up the value chain in terms of economic activity with a significant focus on fourth level training and innovation. The examples drawn on here relate to the biotechnology and information and communication technology (ICT) sectors. With respect to manufacturing Ireland developed a successful foreign direct investment policy that encourage US multinational to establish a European base in Ireland, particularly in the pharmaceutical and ICT sectors. This lead to high levels of economic growth over the period 1998–2002, reaching >10% GDP growth levels per annum, and full employment. The example drawn on for deployment is that of wind energy, which had a slow start due to incoherent policies and then accelerated more recently as these were addressed. Section 3 also draws on the success of the integrated strategy developed in Denmark for wind energy development and identifies key lessons that may be learned.

[1] For comparison, Ireland's total electricity demand in 2007 was 25.9 TWh (Howley et al 2008).

Table 1
Ocean Energy Strategy 2005 proposed phases of wave energy development and supporting grants (condensed version of Table 3 from [17]).

Phase	Year	Ireland Technology Leader	Ireland Technology Taker
Phase 1	2005–2007	€5M	€5M
Phase 2	2008–2010	Yes = €10.5M	Yes = €6.5M
Phase 3	2011–2015	Yes = €19M	Yes = €10.1M
Phase 4	2016–2025	No amount set	No amount set
Total		€34.5M	€21.6M

Table 2
Minister of Energy 2008 statement for Ocean energy Development fund, proposed expenditure for 2008 [20].

1. €1 million towards a world class, state-of-the-art National Ocean Energy facility in UCC. The Facility will now have an advanced wave basin for the development and testing of early ocean energy devices
2. €2 million to support to develop a grid-connected wave energy test site at Annagh/French Point near Belmullet, Co. Mayo
3. €2 million in grants this year under the Ocean Energy Prototype Fund. This will help developers to make their devices commercial
4. The introduction, of a new feed-in-tariff under the REFIT scheme for wave energy of €220 per MegaWatt Hour
5. €500,000 this year to establish an Ocean Energy Development Unit as part of Sustainable Energy Ireland (SEI). Operating with the support and assistance of the Marine Institute, this unit will oversee the implementation of the initiative

Section 4 brings together the key successful elements from Section 3 that may be used to address the gaps identified in Section 2. It points to what will be required to deliver on the Government intent, which is considerably greater than what is currently in place.

This approach may clearly be replicated elsewhere and for other technologies. While energy policies tend to be built on previous experience within energy policy, this paper demonstrates a new approach whereby policies utilised in other sectors can be drawn on to point the way forward for successful wave energy policies. Section 5 draws some conclusions and points to other issues that need to be considered.

2. Establishing the policy goals

2.1. Current status and focus of wave energy policy in Ireland

2.1.1. Wave energy policy before 2008

In 2002 the Marine Institute (MI) and Sustainable Energy Ireland (SEI)[2] undertook a joint consultation exercise to build consensus around a strategic approach to wave energy development in Ireland [6]. Prior to this there was limited research funding available for resource assessment and device development but no clearly defined ambition. The consultation document suggested three options distinguished in terms of strategic objective, risks, expenditure and benefits. Option 1 focused on Ireland becoming a wave and tidal energy technology leader, option 2 on the development of an exportable core of research excellence and option 3 on maintaining a watching brief on wave and tidal energy. In parallel with the consultation process, MI and SEI funded work on the economic benefits of ocean energy [15], the offshore wave energy resource in the Republic of Ireland [13] and a development and evaluation protocol for Irish device developers [16].

Funding of approximately €120,000[3] was made available for a 1/4 scale test site in Galway Bay in 2002 by MI and SEI, providing a wave energy test zone where environmental impact assessments were waved for developers.

Based on the responses received during consultation, together with the results of the commissioned studies, MI and SEI published an Ocean Energy Strategy document [17]. The strategy comprised four distinct phases relating to research and development, pre-commercial demonstration, pilot wave energy array and large scale market deployment (Table 1). The total funding proposed at the time ranged from €21.6 M to a high of €34.5 M depending on whether an indigenous manufacturing industry is established or whether the devices would be imported.

Phase 1 stretched from 2005 and 2007. In that time period, €1.25 M of funds was dispensed for R&D in the Hydraulics and Maritime Research Centre (HMRC) via the Blue Power scheme, with matching funds from University College Cork.[4] A further €3.6 M for product R&D as well as €0.08 M for the Bellmullet test site was proposed to be allocated in that time period but was not appropriated[5]. However, €1.1 M of funds were appropriated to industry via Sustainable Energy Ireland (SEI) from 2005 to 2008,[6] with other lesser funds administered by Enterprise Ireland (EI) and MI.

In 2007, the Irish Government White Paper on Energy [18] increased the existing targets and funding for wave energy. Here the Government specified an 'initial ambition' of 75 MW by 2012 and at least 500 MW of installed ocean energy capacity by 2020 (originally 485 MW by 2025) [14,19], effectively accelerating the ocean energy strategy timeframe by 5 years. The White Paper also contained the Government intent to 'make Ireland a world leader for research, development and deployment of ocean energy technologies.

2.1.2. Current wave energy policy–beyond 2008

In January 2008, over €26 million of funding for an Ocean Energy Development fund was announced by the Minister for Energy for the sector spanning a 3 year period till 2011 [20]. The funding in effect superseded the funding outlined in the 2005 Ocean Energy Strategy document for Phase 2 and possibly Phase 3. Table 2 lists the indicative funds which were proposed to be allocated in 2008. The policy initiatives stemming from the 2008 announcement may be categorised according to the focus areas of this paper, i.e. whether they support innovation, manufacturing or deployment, drawing on the results of [21].

2.1.2.1. Policies supporting innovation (Ireland). The Ocean Energy Development Fund is dominated by support for innovation. Table 3 lists recorded spending from the fund for 2008 and 2009, and proposed spending until 2011.[7]

2.1.2.1.1. Research and test centre. The Hydraulics and Maritime Research Centre[8] (HMRC) in University College Cork operates wave energy test tank facilities and also provides independent consultancy and design support to technology developers. The Centre offers support with physical model testing, concept design, computer modelling, device performance validation, resource assessments and offshore data monitoring. €1 M was allocated and spent in 2008 and €1.5 M in 2009 towards equipment upgrade

[2] http://www.sei.ie/Renewables/Ocean_Energy/Wave_Energy_Research_in_Ireland/.
[3] Personal communication Owen Sweeney (OEDU).
[4] Personal communication Tony Lewis (HMRC).
[5] Personal communication Owen Sweeney (OEDU).
[6] Personal communication Brian O'Mahony (SEI).
[7] The majority of the table information was sourced from a personal communication from Brian O'Mahony, SEI.
[8] http://www.ucc.ie/research/hmrc/.

Table 3
Actual and future indicative spending of the Ocean Energy Development fund (personal communication with Brian O'Mahony (SEI) and Richard Browne (DCENR).

	2008	2009	2010 (proposed)	2011 (proposed)
R&D (HMRC)	€1M	€1.5M	€4M (indicative)	
R&D (Charles Parsons Fund)	€3.47M (till 2014)			
Prototype fund	€0M	€10M (indicative 2009 to 2011)		
Test site	€0M	€10M (indicative 2009 to 2011)		
Marine Institute R&D		€0.3M	€0.1M	€0.1M
OEDU operations		€0.25M	€0.25M	€0.25M
OEDU consultation		€0.36M	€0.36M	€0.36M
Tariff (€0.22/kWh)	€0M (not expected to be drawn upon till after 2011 and funds to accessed from Public Service Obligation (PSO) Levy)			

and additional facilities, with a further indicative capital program of approximately €4 M for future construction of a new building to house new facilities [22].

Further centres of research include Limerick University, Maynooth University and Queens University.

2.1.2.1.2. Prototype fund. €2 M was assigned in 2008 to support ocean energy developers in making their devices commercial. Due to the delay in setting up the OEDU in 2008 and further administrative delays persisting into mid 2009, the funds were not administered until Oct 2009. A total indicative sum of €10 M funding will be made available to developers from 2009 to 2011. €18 M worth of projects have already applied for this funding.

2.1.2.1.3. Test site. The Ocean Energy Development Strategy plans for a grid-connected wave energy test site at Annagh/French Port near Belmullet, Co. Mayo, capable of accommodating 5 berths totalling 5MW. Environmental impact assessment (EIA) will be carried out, and grid connection and offshore cabling will be included in the project development. Due to the delay in set-up of the OEDU, the €2 M allotted for 2008 was not dispersed and spent. An indicative sum of €10 M is proposed till 2011, which is hoped to cover the cost of getting the site operational (cabling, connection etc). Details of the plan for the test site are still being developed. Final budget will be dependant on the result of site investigations which are currently underway, with the final near-shore survey to start soon, followed by geotechnical ground investigation works. It is possible that the cost of installing the test site may be much larger. A study by the author indicated that the cost could vary from €8 M to €17 M depending on the number of cables and layout, but could be higher according to other as yet unpublished reports.

2.1.2.1.4. OEDU[9]. The Ocean Energy Development Unit was established in late 2008, with an allocated fund of €0.5 M in 2008. The following studies will be commissioned by the unit:

- Economic feasibility study (carried out by SQW Energy).
- Strategic Environmental Assessment[10] (SEA).
- Engineering studies (carried out by ESBI).

2.1.2.1.5. Tariff. As the test site will not be operational till post 2011, funds for the tariff will not be taken from the €26 M development fund. Funds for the tariff will be sourced from the Public Service Obligation (PSO) Levy (more details in the next section).

2.1.2.1.5.1Additional R&D funding. In parallel with the funding delivered in accordance with the Ocean Energy Strategy, additional funding for innovation of €3.47 M has been secured for wave energy research for the Charles Parsons Energy Research Awards[11] to support 4 researchers, 3 PhD students (4 years) and 2 summer placements (each year) in the HMRC running until 2014 [23].

2.1.2.2. Policies supporting manufacturing (Ireland). There are currently no policies in Ireland which are specifically targeted for supporting wave energy manufacturing industry in Ireland. There are significant supports available for manufacturing as outlined in Section 3.1.2 and a number of these may be accessed for wave energy manufacturing.

2.1.2.3. Policies supporting deployment (Ireland). Policies supporting renewable energy deployment typically focus on capital grant support (at an early stage of development) followed by market support (generally in the form of a feed in tariff or obligation on suppliers). In Ireland the feed-in tariff and targets are the policies that most stimulate wave energy deployment. Provision of a tariff can also stimulate innovation by facilitating revenue returns for testing (discussed in the above section), but is principally intended to support deployment.

2.1.2.3.1. Revenue support–Feed-in Tariff (FIT or REFIT). A feed-in-tariff under the REFIT scheme was introduced by the Minister of Energy in 2008 [20,24] for wave energy. The tariff offered is €0.22/kWh and is primarily aimed at supporting device deployment in Belmullet test site, which has a planned capacity of 5 MW. However, the tariff will also be available for other wave and tidal projects until approximately 2015, with project finance available for a 15 year period.[12] In that timeline till 2015, the tariff will not be constrained by wave farm size, and pertains to both commercial and demonstration deployment. Furthermore, there will not be a sliding scale of tariffs both in relation to size of the development or reduce sequentially with time. Subsequent to that date, there will likely be a scaled tariff rate available similar to the Portuguese scheme, detailed in a later section of this report. It is not anticipated that the test site nor any device will be ready before 2011, thus funding for the tariff will be not be sourced from the Minister's €26 M, but will be derived from the from the Public Service Obligation (PSO) Levy.

2.1.2.3.2. Targets. A 500MW target for installed wave energy by 2020 has been currently set by DCENR [14] in its white paper. However, it is quoted in the paper only as an 'ambition', although adding that 'at least' 500 MW would be the desired minimum. The 500 MW target is an increase from that originally set in the 2005 strategy paper of 84 MW installed by 2020 and 485 MW for 2025. The white paper also set a short range target of 75 MW for 2012. This target was cancelled in Sept 2009 by the OEDU,[13] as it was deemed unattainable considering current progress in device development at the time.

2.1.2.3.3. Grid network upgrades. A total of €4B has been allocated under the Grid 25 plan to the ESB and ESBI for the upgrade of the State transmission network to cater for increase renewable energy penetration over the next decade [25]. The funds have been split regionally as follows: North West €750 M, North East €300 M,

[9] http://www.sei.ie/Renewables/Ocean_Energy/Ocean_Energy_Development_Unit/.
[10] http://www.sei.ie/Renewables/Ocean_Energy/Offshore_Renewable_SEA/.
[11] http://www.sfi.ie/content/content.asp?section_id=742&language_id=1.
[12] Personal communication from Richard Browne (DCENR).
[13] Personal communication from Owen Sweeney (OEDU).

West €315 M, East €800 M, Midlands €310 M, South West €730 M, South East €830 M. There has been no further announcement of time frames for implementing the project or detailed specifics of the upgrades at the time of publication of this paper.

2.2. Wave energy policy elsewhere

It is useful to compare policy developments in Ireland with those elsewhere, in order to draw insights into additional measures that may be usefully employed in Ireland. Table 4

Table 4
Wave energy policy in Europe relative to the industry sectors of innovation, manufacturing and deployment. (X implies not existing or no current information, NR implies not relevant).

Countries	Strategies	Innovation	Manufacturing	Development/deployment
Ireland	Tariff	€0.22/kWh	NR	€0.22/kWh
	National strategy	√	×	√
	Targets	NR	×	75 MW 2012 500 MW 2020
	Grants	€3.5M Parsons fund for all energy research €10m prototype research (estimate)	×	×
	Test site + commercial sites	Belmullet 5 MW, €10M (estimate)	NR	NR
	Grid connection charges	NR	NR	Shallowish
Portugal	Tariff	<20 MW, €0.26/kWh 20–100 MW, €0.21/kWh	NR	<100 MW, €0.16/kWh 100–200 MW, €0.11/kWh >250 MW, €0.075/kWh
	National strategy	×	×	×
	Targets	NR	×	50 MW 2010 550 MW 2020
	Grants	PRIME- DEMTEC + QREN €6M	×	×
	Test site + commercial sites	250 MW (planned)	NR	250 MW (planned)
	Grid connection charges	NR	NR	Deep
Spain	Tariff	NR	NR	€0.06/kWh + €0.05/kWh
	National strategy	×	×	×
	Targets	NR	×	5 MW by 2010
	Grants	PSE-Mar- €25M	×	×
	Test site + commercial sites	BIMEP 20 MW, €15M Mutriku 0.3 MW, €6M Santona 1.35 MW, €3M	NR	Test sites could become commercial
	Grid connection charges	NR	NR	Deep
UK	Tariff	1ROC = 0.045/kWh UK 2 ROC Scotland 5 ROC	NR	1ROC = 0.045/kWh UK 2 ROC Scotland 5 ROC
	National strategy	×	×	×
	Targets	NR	×	×
	Grants	Carbon Trust: £3.5M MRDF: pre-commercial funds Scotland: SEMEF- £13M Saltire Fund- €10M	×	ETI matching funds to £1B MRDF: £50M
	Test site + commercial sites	EMEC 20 MW, £14M Wave Hub 20 MW, £26M (planned)	NR	Test sites could become commercial
	Grid connection charges	NR	NR	Shallowish
Germany	Tariff	€0.06/kWh	NR	€0.06/kWh
	National strategy	×	×	×
	Targets	NR	×	×
	Grants	×	×	×
	Test site + commercial sites	×	NR	×
	Grid connection fee	NR	NR	Shallow
France	Tariff	€0.15/kWh	NR	€0.15/kWh
	National strategy	×	×	×
	Targets	NR	×	×
	Grants	×	×	×
	Test site + commercial sites	SEM-REV 2 MW, €5M	NR	×
	Grid connection charges	NR	NR	Shallow
Denmark	Tariff	€0.08/kWh + 0.05/kWh	NR	€0.08/kWh + 0.05/kWh
	National strategy	×	×	×
	Targets	NR	×	×
	Grants	RTD - €13M	×	×
	Test site + commercial sites	Nissum Bredning	NR	×
	Grid connection charges	NR	NR	Shallow
Italy	Tariff	€0.34/kWh + 1.8 ROC	NR	€0.34/kWh + 1.8 ROC
	National strategy	×	×	×
	Targets	NR	×	×
	Grants	×	×	×
	Test site + commercial sites	×	NR	×
	Grid connection charges	NR	NR	Deep

Table 5
Wave energy research and test centres in Europe [26].

UK	New and Renewable Energy Centre (NaREC) based in Northumberland, UK SuperGen is a consortium of universities funded by the UK Engineering and Physical Sciences Research Council (EPSRC) HR Wallingford University Cardiff University University of Plymouth's Marine Institute
France	Laboratoire de Mécanique des Fluides (LMF) de l'Ecole Centrale de Nantes Palaiseau, INSA (wave basin) Chatou, LNHE (wave basin)
Portugal	INETI–Instituto nacional de Engenharia Wave Energy Centre - WAVEC[71], founded in 2003. University of Porto (wave basin)
Spain	CETMAR is a Technology Centre (Public Foundation)
Denmark	DHI Water and the Environment Technical University of Denmark, ISVA Aaborg University
Norway	Norway University of Science and Technology

[71] http://www.wavec.org/.

presents Ireland's wave energy measures in addition to those in place in a number of other EU Member States. The discussion of Table 4 focuses on the three distinct policy goals of innovation, manufacturing and deployment.

2.2.1. Policies supporting innovation (Europe)

2.2.1.1. Research centres. Research centres form the foundation for nascent innovation in technology. The majority of these centres also contain wave tanks which facilitate prototype device testing and analysis. Table 5 lists the wave energy research and test centres (with wave basins) across Europe.

2.2.1.2. Grants. There are a multitude of grants schemes provided by other European countries to support wave energy innovation. Perhaps the most comprehensive is that provided by the UK. These consist of:

- Marine Energy Accelerator (MEA) (2006) £3.5 M to accelerate progress in cost reduction of marine energy (wave and tidal stream energy) technologies.
- Marine Renewables Deployment Fund (MRDF) (total £50 M), aimed at the early stage pre-commercial operation and sea trials of a number of wave and tidal current energy technologies [4].
- Marine Renewable Proving Fund 2009 (MRPF) (£22) [27], aims to accelerate the leading and most promising marine devices towards the point where they can qualify for the MRDF. The fund is administered by the Carbon Trust and uses new funding provided by the Department of Energy and Climate Change (DECC). Up to £6 m is available to successful applicants to help meet the capital costs of building and deploying wave and tidal stream prototypes. The MRPF will provide up to 60% of the eligible project costs.

Scotland has set up a number of separate support schemes for ocean energies:

- The Scottish Executive Marine Energy Fund (SEMEF)[14]—aims to support the development of key technologies and processes that will enable measurable growth in the Scottish Marine Energy sector. Projects targets include subsea connectors, oceanographic instruments, anchoring & seabed monitoring devices, direct drive low speed generators.
- The Scottish Executive has named nine marine energy projects (WATES) that will share grants worth more than £13 M [28,29]. The largest grant goes towards Scottish Power's scheme to moor four floating generators, designed to convert wave movement into electricity, off the European Marine Energy Centre (EMEC) in Orkney.
- Saltire Prize - £10 M will be awarded to a project that can demonstrate a commercially viable wave or tidal energy technology in Scottish waters. The project device must achieve a minimum electrical output of 100GWh over a continuous 2 year period using only the power of the sea[15].

In Spain, the Special Strategic Marine Energy Project (PSE-MAR) is co-funded by the Ministry of Education and Science and aims to position Spain as a world leader in the marine energy sector [29,30]. The project, coordinated by Technalia,[16] has a budget of €25 M for 2005–2009 (or €35 M for the period 2008–2010[17]) and focuses on the development of three of the most promising Spanish technologies for harnessing wave energy–the technologies developed by PIPO Systems, Hidroflot and OceanTec.

In Denmark, special grants exist for support of R&D and €13 M (4 × 25 M. DKK) have been allocated for the period up to 2011 for wave energy and other emerging energy technologies [31]. In Portugal, PRIME-DEMTEC[18] (2000–2006) was a fund of approximately €6 M to support more than 21 innovative technologies and this is being continued by QREN (2007–2013) [31].

2.2.1.3. Test sites. The necessity for nationally funded test sites to support research for local technologies has been recognised by many countries in Europe. To date, six countries have provided funds for their development.

The UK has most advanced test sites, and has received recent funds of $38 M for ocean energy of a total £60 M[19] from the Low Carbon Transition Plan 2009. The sum of £9.5 M was allocated for Wave Hub, £10 M for a world centre for wave and tidal energy in the South West UK's, £10 M for testing facilities at the National Renewable Energy Centre in Northumberland and up to £8 M for the European Marine Energy Centre in the Orkneys.

[14] http://www.hi-energy.org.uk/Default.aspx.LocID-06gnew02v.RefLocID-06g008001001.Lang-EN.htm.

[15] http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Action/leading/saltire-prize.

[16] http://www.tecnalia.info/down/Energia_Tecnalia_eng.pdf.

[17] http://www.waveplam.eu/page/default.asp?id=192.

[18] http://www.prime.min-economia.pt/PresentationLayer/prime_Noticias_00.aspx?activeitem=7&activesubitem=0&idioma=2&accaoid=92&noticiatipoid=1.

[19] http://www.wave-tidal-energy.com/home/news-archive/41-government-regulatory/211-uk-government-to-invest-p60m-in-wave-and-tidal-energy.

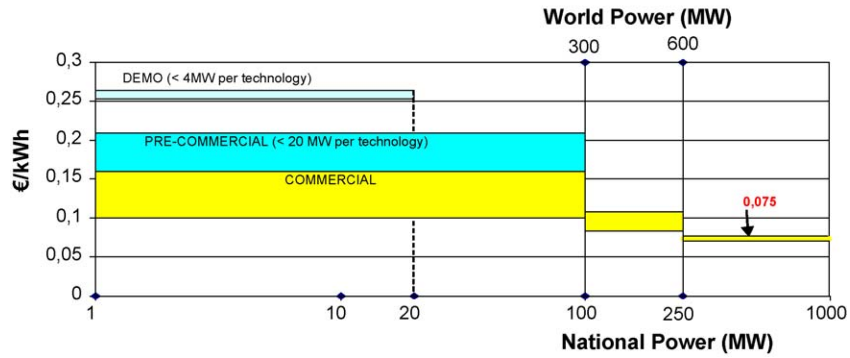

Fig. 1. The proposed range of FIT offered in Portugal for the various stages of R&D and capacity deployed [35].

The European Marine Energy Centre[20] (EMEC) currently provides the worlds only multi-berth 20MW, purpose-built, open sea test facilities to date for wave and tidal energy converters, and received an initial setup fund of £16 M investment [32]. There are two test sites:

- Wave energy test site: Billia Cro, Orkney. Four test births in 50 m of water.
- Tidal energy test site: fall of Warness, Island of Eday.

A fee is charged which covers cable and connection costs.

The other UK test site is the proposed WaveHub[21] off Cornwall. In the current proposals, it will have connections for four kinds of wave energy converter with a total capacity of 20MW and funding of over £40 M (South West RDA -£21.5 M, Department of Trade and Industry £9.5 M, £20 M from European Regional Development Fund [33]). Currently there are three wave device developers confirmed. The three confirmed developers are:

- Fred Olsen Limited
- Orecon Ltd.[22]
- Ocean Power Technologies (OPT) Limited

Energy company E.ON and partner Ocean Prospect who will be using the Pelamis device, withdrew from the Wavehub test site in 2009 and will now be testing in EMEC.[23]

Portugal are planning a test site called the Pilot Zone, facilitating 80 MW in the first phase and 250 MW in the second phase [30]. The zone will be supervised by a Management Body, which will facilitate 'One-stop shop' planning/permit application, grid connection and cable, EIA and data collection support infra-structure. The service has to be paid for by the developers via a rent. There are still a number of unclear issues regarding financial and planning details needing to be discussed [31]. "The initial plans to have the pilot zone operational already shifted from 2009 to now 2010, which only in the ideal case will be possible, and also only for a fraction of the planned zone".

Spain has three tests planned or already in operation. The first is in Mutriku, in the Basque country. It consists of an oscillating water column integrated in a breakwater.[24] The total investment is €6 M investment, €4 M for civil work and the rest for electromechanic work and grid connection. The plant consists of 16 turbines, 18.5 kW each, with an estimated overall power of 296 kW. The Basque country is also proposing plans for a larger fully serviced test site, BIMEP [34]. It will consisting of 4 berths and total of 20MW capacity costing €13 M. Facilities will include cable and data monitoring. The site is due to be operational by the end of 2010. The third site is based in Santona, Cantabria, where Iberdrola Energías Marinas de Cantabria S.A plan to test OPT's Powerbuoy.[25] The site will include grid connection for 9 buoys of 150 kW each. Affiliated groups involved are Iberdrola Renovables, Total, OPT, IDEA and Sodercan. The budget for the first phase, which includes the electrical marine infrastructure, amounts to €3 M.

Other smaller test zones proposed or operational are:

- France: 2.5MW SEM-REV[26] test zone of the coast of Nante, €5.5 M funding, which includes cable and instrumentation.
- Denmark: Nissum Bredning used for testing Wavedragon[27].

2.2.1.4. Tariff support for demonstration projects. Deployment of devices in tests sites which produce electricity to the grid is essential part of the R&D process for wave energy device development. Device innovators will need to be reimbursed for the electricity they supply to the grid in order to finance the cost of connection and possible upgrades to the network required. Portugal is the only other country in Europe besides Ireland (which has already been discussed) which has tailored tariff support for demonstration projects, promising €0.26/kWh for the first five demonstration projects, with total output of 20 MW [35] (Fig. 1). Other countries advertise FIT, but for undesignated project sizes and purposes. These are discussed in the following sector under deployment.

2.2.2. Policies supporting manufacturing (Europe)

The authors found no policies currently in place in other Member States which target support specifically for wave energy manufacturing. However, there are a number of supports for manufacturing in many Member States that may be drawn on to support wave energy.

2.2.3. Policies supporting deployment (Europe)

The support mechanisms available in other Member States for deployment of wave energy devices comprise capital grants (only available in the UK) and feed in tariffs (or ROCs in the UK). Aspects of the capital grant support, FIT and targets included here could also be considered as innovation support.

2.2.3.1. Capital grants. The only country in Europe which has grant funding tailored for the deployment sector is the UK. Other EU

[20] http://www.emec.org.uk/facilities.asp.
[21] http://www.wavehub.co.uk/.
[22] http://www.orecon.com/en/news/wave-hub-chooses-orecon-as-new-device-developer/.
[23] http://pressreleases.eon-uk.com/blogs/eonukpressreleases/archive/2009/04/29/1380.aspx.
[24] http://www.waveplam.eu/page/default.asp?id=192.
[25] http://www.waveplam.eu/page/default.asp?id=192.
[26] http://www.oreg.ca/docs/2008_Fall_Symposium/Mouslim.pdf.
[27] http://www.wavedragon.net/index.php?option=com_content&task=view&id=12&Itemid=14.

Member States do have capital grant support available but for pre-commercial deployment which is already covered in Section 2.1.2.3 and considered a support for innovation.

The Wave and Tidal Stream Energy Demonstration Scheme is a scheme within the Marine Renewables Deployment Fund (MRDF) [4], with funds of £42 M out of a total £50 M. The scheme will support the deployment of multiple, full-scale wave or tidal stream electricity generating devices connected to the UK grid. It will do this through a combination of capital grants (25% of eligible costs) and revenue support (£0.10/kWh in place for a maximum of 7 years from commissioning). Funding covers grid connection and infrastructure costs.

The second source of funding is provided by the Energy Technologies Institute[28] (ETI). Its supports development and demonstration projects in marine energy, and is a public/private partnership backed by companies including BP, Caterpillar, EDF Energy, E.ON, Rolls-Royce and Shell. Its target is to secure up to 11 private sector investors, each contributing £5 million per year for 10 years, with the UK Government matching these investments to create a potential £1 billion investment fund for new energy technologies [36].

2.2.3.2. Feed-in tariff (FIT)/Renewable Obligation (RO). The majority of Western European countries with Atlantic access have proposed some form of Power purchase agreements (PPA). Feed-in tariff (FIT) schemes instead of renewable obligations (RO) are the most prevalent in Europe. Italy leads with the highest proposed tariff of €0.34/kWh [37]. Portugal follows with the perhaps the most developed tariff scheme. Five pre-commercial projects will be supported of 20 MW each, with FIT of €0.16/kWh [35] (Fig. 1). FIT rates for commercial projects range from €0.16/kWh for under 100MW farms, €0.11/kWh for 100–250 MW and €0.075 for farms over 250 MW.

France, Denmark Spain, and Germany also have FIT which are respectively, €0.15/kWh, €0.08/kWh, €0.06/kWh and €0.06/kWh [38], however it is uncertain as yet as to whether these tariffs pertain to demonstration, pre-commercial or commercial projects,and whether they will scaled for larger projects.

The UK has placed a Renewable Obligation on electricity suppliers, mandating them to deliver a certain proportion of their electricity from renewable sources, evidenced each year through the submission of the appropriate amount of Renewable Obligations Certificates (ROCs). ROCs are distributed to each renewable energy generator for each MWh of electricity sold. This effectively establishes a market ROCs that is separate to the market for electricity. The price of a ROC in 2008 was approximately £0.047 [39]. From April 2009, two ROCs will be issued for each MWh of wave generated electricity in England and Wales (equating to a value currently of £0.09/kWh), that is supplementary to the price received for the electricity). In Scotland five ROCs will be allocated for each MWh of wave generated electricity (equating to £0.225/kWh based on current prices), also in addition to the electricity market price.

2.2.3.3. Targets and leases. Targets are becoming increasingly recognised as driving engines for action. Some targets, such as atmospheric pollution reduction, are legally binding international commitments. Wave energy targets currently reflect the aspirations of national governments. Two countries in Europe besides Ireland have proposed targets for wave energy deployment. Portugal's National Strategy for Energy in 2001, set a target of 9680 MW for additional electricity generating capacity from renewable energy systems (RES) by 2010, of which 50 MW referred to wave energy [4], but still to be ratified [40]. This target has recently been increased to 550 MW by 2020.[29] Spain is the other country with a target policy and has set a 5 MW installed capacity goal for 2010[30] in the Basque country, and 50 MW for the Canary Islands by 2015.[31]

The UK has bypassed targets, and has commissioned the Crown Estate to extend a round of leasing opportunities in the Pentland Firth/Orkney/North Sutherland area of Scotland.[32] Thirty eight companies have successfully pre-qualified in early 2009.

2.2.3.4. Grid upgrades and reinforcements. The capacity of European grid transmission and distribution system to incorporate large amounts of renewable energy is being increasingly challenged. In the majority of European countries, national grids were designed to accommodate central generation, resulting in weak transmission lines available in coastal areas. The coastal areas of Ireland and Scotland are poorly serviced by high capacity transmission networks. Considerable grid upgrading and reinforcement will be required for the introduction of large scale wave energy farms. Several studies at national and European level are now underway to back up the plans for upgrading the European transmission system, in order to facilitate large-scale renewable integration. The most important international studies are the European Wind Integration Study[33] (EWIS) and TradeWind.[34]

Countries with existing high capacity grid systems and interconnectors include Denmark, which does not plan reinforcements in any "anticipation of need/strategic way" [41]. Coastal areas with good transmission systems include Portugal and SW UK [31].

In the UK, the Electricity Networks Strategy Group (ENSG) quoted that approximately €6.5B will be needed to upgrade the network for renewables.[35] The Highlands and Islands Enterprise (HIE) has commissioned Xero Energy to carry out a grid upgrade study.[36] This estimated that the grid upgrades required in the North of Scotland alone could cost between £150 M and £435 M. There are plans to upgrade connections of the Beauly–Denny 400 kV overhead electricity transmission line which will replace the existing 132 kV transmission line between Beauly, west of Inverness, and Denny, west of Falkirk [41]. The proposed upgrade to the overhead electricity transmission line will enable the Western Isles to be opened up to WECs, and is currently subject to a public inquiry.

Germany has plans for 850 km of new transmission lines.[37] In Spain, reinforcement works and extensions will total around €500 M [41]. In the regions with major RE wind power development, reinforcement measures are planned involving approximately 250 km of new 230 kV lines, and over 1600 km of 400 kV lines. This does not however constitute strategic grid planning as such but is an anticipation of things to come. Italy has approached the network issue by installing 30 million smart meters in Italian homes since 2001.[38] Although customers only

[28] http://www.energytechnologies.co.uk/Home/Technology-Programmes/marine.aspx.

[29] http://www.unep.org/climateneutral/Default.aspx?tabid=803.

[30] http://download.southwestrda.org.uk/interes/interest-event-bristol/wave energy.pdf.

[31] http://www.waveplam.eu/page/default.asp?id=192.

[32] http://www.waveplam.eu/page/default.asp?id=260.

[33] http://www.wind-integration.eu/downloads/library/2009-02-05-EWIS-Offshore-Onshore-Grid-Perspectives.pdf.

[34] http://www.trade-wind.eu/.

[35] http://www.rechargenews.com/business_area/innovation/article173405.ece.

[36] http://www.waveplam.eu/page/default.asp?id=260.

[37] http://www.wind-integration.eu/downloads/library/2009-02-05-EWIS-Offshore-Onshore-Grid-Perspectives.pdf.

[38] http://www.smartgridnews.com/artman/publish/news/Energy_bill_could_hit_utilities_hard_NIST_accelerates_standards_efforts_Consumers_could_block_demand_response_Ember_s_cash_cup_runneth_over-559.html.

Table 6
Funding agencies for research in Ireland since 1998.

Funding agency	First year of funding	Funding focus
Science Foundation Ireland (SFI)[a]	2000	SFI supports academic researchers and research teams, investing €1.4 billion[b] •Biotechnology •Communications and IT
Enterprise Ireland (EI)[c]	1998	Development and promotion of the indigenous business sector •R&D Funding •Innovation Vouchers •Technology Acquisition 2009 budget is €134M[d]
Irish Research Council for Science, Engineering & Technology (IRCSET)[e]	2001	IRCSET academic research funding for the sciences, engineering and technology. Funding for 2008 was €26.5M[f]
PTRLI-4[g]	2007	€260 million 17 projects
PTRLI-5[h]	2010	Commencing in 2010, €300m physical infrastructure, Ph.D. education
Strategic Innovation Fund (SIF)[i]	2006–2013	€510M support for innovation in higher education institutions

[a] http://www.sfi.ie/content/content.asp?section_id=207&language_id=1.
[b] [52].
[c] http://www.enterprise-ireland.com/Publications/.
[d] [52].
[e] http://www.ircset.ie/Default.aspx?tabid=36.
[f] [54].
[g] http://www.hea.ie/en/node/1196.
[h] http://www.hea.ie/files/files/file/PRTLI%20Cycle%205/PRTLI%20Cycle%205%20Call%20text.pdf.
[i] http://www.hea.ie/en/sif.

save about $1.5 Euros a month, the Italian utility ENEL has paid back its 2.2 billion Euro investment in just 4 years.

2.2.3.5. One stop shops and Strategic Environmental Assessments (SEA). Scotland completed the SEA in 2009 [42], overseen by the newly formed Marine Scotland.[39] In Spain, the Spanish Royal Decree 1028/2007 established a simple licensing procedure for wave energy installations [31] and is administered by authorisation General Direction for Energetic Policy and Mines [43]. However, it is still not clear how to apply for the BIMEP test zone [31]. Portugal has also recently introduced simplified planning application rules, but at present will only apply to the Pilot zone [44]. The Danish regulatory framework system is based on the "one-stop-shop" principle for off-shore wind and ocean, creating a simplified system for EIA and consent, with a much lower degree of uncertainty [45].

3. Successful policies for innovation, manufacturing and deployment in other sectors, examining Ireland and Denmark

Section 2 demonstrated that while ambition exists in Ireland and elsewhere to develop and deploy wave energy technology, there remains a significant gap between the ambitions and the measures and policies required to deliver. This section presents other industry sectors, both in Ireland and in Denmark, which were successful in reaching and economic maturity, and examines the policies that supported that success.

3.1. Ireland

3.1.1. Policies stimulating innovation

In the light of Ireland's eroding cost advantage in the 1990s, there was a shift in focus from securing manufacturing activities to higher value added activities, such as advanced manufacturing and research and development (R&D) [46]. Policy change was marked firstly by the publication of the Culliton Report [47] culminating in the establishment of the Science Technology and Innovation Advisory Council (STIAC) in 1995. The next year saw the publication of the White Paper on Science Technology and Innovation [48]. This was followed in 1997 by the formation of the Irish Council for Science, Technology and Innovation (ICSTI),[40] under Forfás, to advise Government on the strategic direction of STI policy. The main recommendation of the ICSTI overview report was to develop a vision of Ireland as a knowledge-based society, where the key drivers of growth in the future would be in the areas of ICT and biotechnology. Science innovation became an increasing focus for job creation strategy for the Irish government after 2000, culminating in the publication of the Strategy for Science, Technology and Innovation report in 2006 [49]. Table 6 list the most recent funding bodies which support a wide range of both academic and industrial research, with a total budget for 2008 of €2.5B, 1.5%GDP[41] [50]. This level is still lagging behind most of the major western economies [51], e.g. 3%GDP for the USA and Japan, 2% in Australia.

Europe has had a direct impact on Ireland's STI policy through structural funding and the framework programmes, placing a focus on knowledge-intensive industries and increasing spend on R&D. The EU's Framework Programme of Research and the ESPRIT[42] program channelled 2% of EU GDP into Ireland [11]. Closely related to the ESPRIT programme was the Programmes in Advanced Technologies[43] (PATs), which was one-third supported by the European Regional Development Fund[44] (ERDF).

The Irish government also has a R&D tax credit of 25% which can be offset against a company's corporation tax liability [52]. Since the Tax Credit was first introduced in the Finance Act 2004, private sector investment in R&D increased significantly to an estimated €1.56 billion in 2006, almost double the level recorded in 2000. However, the tax relief for innovation is still much smaller than some international countries; e.g. Australia[45] 40–45%. The UK R&D tax credit allows companies to set 125% of eligible R&D against taxable profits or 150% for SME companies [53]. Capital expendi-

[39] http://www.seaenergyscotland.co.uk/.

[40] http://www.irishscientist.ie/p42-43.htm.
[41] http://www.src.ie/news/other_research/application_dates.pdf.
[42] http://cordis.europa.eu/esprit/home.html.
[43] http://www.irishscientist.ie/2001/contents.asp?contentxml=01p146.xml&contentxsl=IS01pages.xsl.
[44] http://ec.europa.eu/regional_policy/funds/prord/prord_en.htm.
[45] http://www.ausindustry.gov.au/InnovationandRandD/RandDTaxCredit/Pages/RandDTaxCredit.aspx.

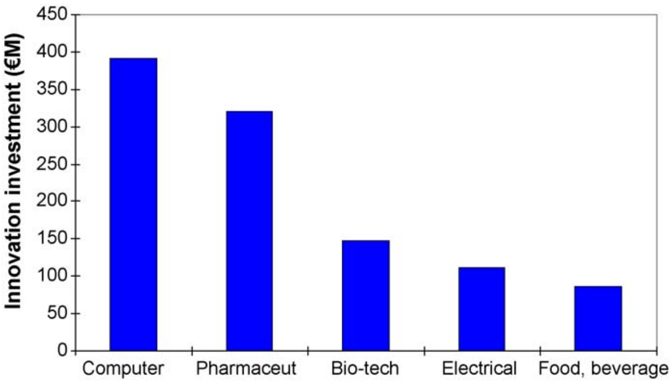

Fig. 2. Industry sectors in Ireland which are investing the largest funds in innovation (sourced from Survey of R&D in the Business Sector, 2007/8 which was published in [55].

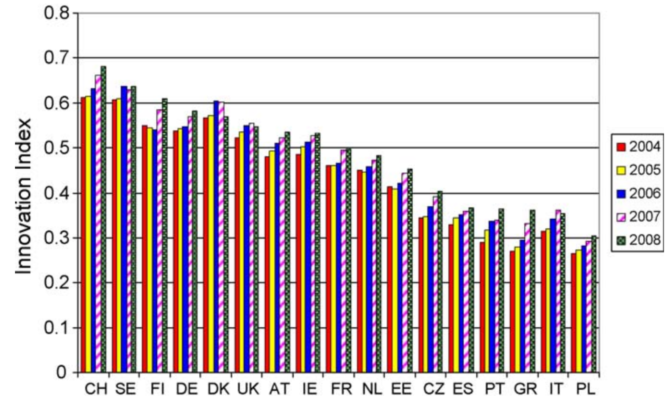

Fig. 3. Innovation index. Data taken from Annex D [56].

ture on R&D, including buildings, also attracts a generous 100% first year allowance.

Government investment support for innovation in industry has led to industry financing their own innovation research, with investments sums totalling €1B 2007/2008 (Fig. 2).

From 2004 to 2008, successful policies in innovation has led to an increase in Ireland's Innovation Index score from 0.48 to 0.53 (Fig. 3), and presently lies eighth in the list of European countries surveyed in the European Innovation Scoreboard [56].

3.1.2. Policies stimulating manufacturing

The economic turnaround in the Irish economy is marked by double-digit growth figures [11]. Through much of the last 50 years, Ireland's advantage has lain primarily in manufacturing with a pro-business environment a keystone for many successive governments [57]. The cornerstone policy that drove the success in this sector is almost exclusively due to the low corporate tax regime of 12.5% introduced in 1980s [58]. This incentive was expanded in 2009, making available a 0%[46] rate for the first 3 years of operation.

The employment rate soared from pre-Celtic rates in the 1980s of 15% to a low of 4.4% in 2003.[47] The three main manufacturing sectors contributing to the economy were food, pharmaceuticals and IT, accounting for 76% of manufacturing industry's gross value added (the contribution of industry to economic growth) as shown in Fig. 4. At its peak from 1998 to 2002, manufacturing industry achieved a 14% average annual growth rate. Since 2002, there was a structural shift from manufacturing to construction.

Ireland pursued its economic development path with a great deal of emphasis on exogenous factors, successfully attracting foreign direct investment (FDI), largely through multi-national corporations (MNCs) [11]. FDI in Ireland ranged from a total of US$164 million in 1985, to US$16.32 billion in 2000 [11]. From 1991 to 1998, foreign-owned firms accounted for 95% of the growth in Irish industrial exports and, by 1999, foreign-owned industry accounted for an estimated €38 billion, or almost three-quarters of total Irish exports. The stock of FDI in Ireland in 2002 was equivalent to 129% of gross domestic product (GDP), which placed it top of the Organisation for Economic Co-operation and Development (OECD) listings, far ahead of second-placed Netherlands with 75% of GDP.

FDI in Ireland originated mostly from export-oriented US MNCs (Table 7), which by 1998 were responsible for 70% of Irish industrial exports. Of the 1025 foreign companies with facilities in Ireland, 489 (48%) were American. Of the 127,578 people employed by foreign companies, 89,158 (70%) worked for American companies. Of the $68 billion in 2003 sales revenue from exports by Irish subsidiaries, 75% came from American companies [46].

The main focus for attracting FDI and MNCs to Ireland was the Industrial Development Agency[48] (IDA Ireland). Since its inception in 1949, it sold Ireland's advantages to the US, via its overseas

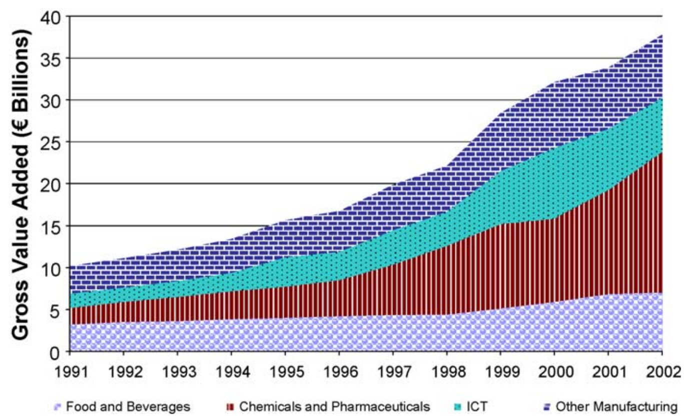

Fig. 4. Gross Value Added in Manufacturing Industry 1991–2002 (Central Statistics Office 2009 Statistics Database available from www.cso.ie).

Table 7
Evolution of Ireland's manufacturing industry, factors for success and example MNCs (adapted from [46]).

	Ireland advantage	Industry type	MNC
1970s	Access EEC Low tax Low cost Capital grants IDA	Manufacturing Pharmaceuticals	Pfizer's Penn Digital Wang
1980s	Educated workforce Government responsiveness	Medical Computers	Bausch and Lomb Lotus Lucent Microsoft Apple Intel
1990s	Clusters Universities	Software Finance services	Dell Citibank Accenture
2000s	R&D Enterprise Ireland Forfas	e-business Bio-pharmaceuticals	EBay Google Wyeth Genzyme

[46] http://www.prlog.org/10258386-register-company-in-ireland-0-corporate-tax-until-2012.html.

[47] http://www.cso.ie/statistics/sasunemprates.htm.

[48] www.idaireland.com.

offices. The agency exploited the US companies' need for a presence in Europe, through attractive incentive packages, including a controversially low corporate tax rate.

An example of MNC success is the software industry. Ireland is cited as the world's second largest software exporter, with software exports valued at US$8bn in 2000 [59]. Ireland produced about 40% of the packaged software sold in Europe and exported some 80% of output. In 2000, some 30,000 people were employed in the industry in roughly 700 firms, of which just over 100 (most of the largest and responsible for nearly 90% of exports) were foreign-owned.

In the last decade, the Irish Government has endeavoured to nurture an indigenous manufacturing base, funded under the state body of Enterprise Ireland.[49] Food is Ireland's single largest indigenous industry with €7B in exports in 2005, and employs 47,000 people directly, with 40% of this figure in indigenous industry [60]. Examples of the largest players in the this sector are the Glanbia Group Innovation Centre, Dairygold Co-operative Society Applied Food Sciences R&D Centre, Kepak Group and Green Isle Foods which in 2005 invested a total of €63 M in innovation.

IT is the other major indigenous success sector, employing an estimated 15,000 people and accounts for about €2B of Ireland's total software exports of €12B [61], representing 5% of the sector in revenue terms [62].[50] Successful indigenous IT companies include Iona Technologies,[51] Sigma electronics[52] and LETSystems.[53]

3.1.3. Policies stimulating deployment

Deployment encompasses any infrastructure installation such as housing, roads and electricity networks. The Irish government has made concerted efforts to support and fund development for Ireland's future, with total funding available in the National Development Plan[54] of €184B till 2013. It provides €54B for investment in economic infrastructure and €20B for enterprise, science and innovation.

Irish wind energy deployment has been successful despite considerable initial delays and setbacks that were associated with incoherent policy decisions. It is an appropriate example to use in this paper as the deployment of wind and wave energy have a number of similar characteristics. They both represent new renewable energy technologies (wave energy now, wind energy in the early 1990s) that require:

- new approaches to spatial planning as new infrastructures on the landscape or seascape,
- changes to the electricity network configuration and operation that traditionally delivers electricity from high voltage connected large scale thermal power plants through a transmission and distribution networks to medium and low voltage connected customers,
- fair and appropriate treatment as new electricity suppliers within the electricity market.

Wind energy deployment was slow during the 1990s and early 2000s but accelerated rapidly since 2003 [63]. By 2009, there was 1.2 GW[55] of installed wind generating capacity in the Republic of Ireland, representing 15% of total installed generating capacity[56] (Fig. 5).

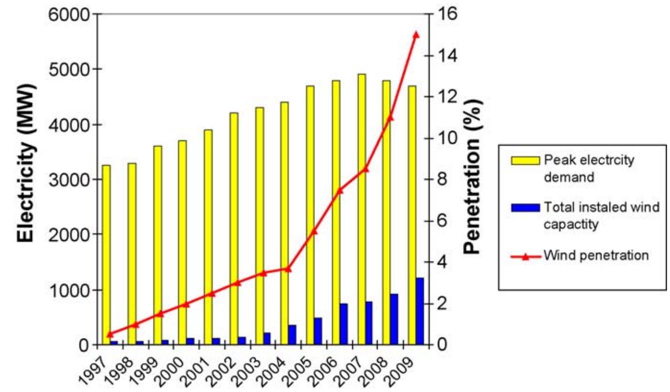

Fig. 5. Historical growth in Irish electricity demand, installed wind capacity and wind penetration (information from Eirgrid, [64], [65]).

The initial support for wind energy in Ireland was in the form of an EU capital grant for the 6.5 MW Bellacorrick wind farm commissions in 1992. Growing interest in renewable energy lead to a target to deploy 75 MW additional renewable energy by 1997 and the introduction of the Alternative Energy Requirement (AER) program to support deployment to meet that target. The AER scheme was a competitive tendering process, similar in design to the UK Non-Fossil Fuel Obligation Scheme [66]. The program had 6 separate competitions (AER I to AER VI) that were implemented over the period 1993–2005. Each competition had a specific target for renewable energy and renewable energy developers were invited to bid in for a guaranteed 15 year Power Purchase Agreement (PPA). Those with the lowest bid unit price for electricity generated were ranked and selected in sufficient numbers to exceed the target installed capacity, thus allowing for some redundancy. There were delays and challenges in meeting the targets initially as there were misalignments between projects that secured AER PPAs and those that had planning permissions. This was addressed in time for the AER V and AER VI competitions,[57] but in this case there was a degree of disconnect between the projects that had AER contracts and those that had grid connection agreements. Throughout the period there were sufficient projects with planning permission, sufficient projects with grids connection agreements and sufficient projects with PPAs to deliver the targets, but the misalignment between these groups of proposed projects resulted in targets not being met. A Renewable Energy Strategy Group was established in 2000 that drew together the policy makers, wind energy developers and the key enablers, namely planning authorities and transmissions and distribution system operators. This group agreed a strategy for wind energy deployment [67] that provided a strong basis for policy decisions going forward. The net effect was low growth to 2003 followed by accelerated growth as indicated in Fig. 6. The AER programme succeeded in supporting the deployment 295 MW wind power out of a target 450 MW.

The AER supported wind deployment was significantly bolstered by merchant plant wind farm development. The Electricity Regulation Act 1999 [68] provided third party access to the electricity network to wind (and other renewable) electricity suppliers to sell directly to all final customers from the year 2000, irrespective of the customer's amount of consumption. Under the Act, brown electricity suppliers could sell only to large customers (>4 GWh per annum). Green electricity suppliers thus had total market access, and in particular to the sections of the market which pay most for electricity (commercial and domestic customers).

[49] http://www.enterprise-ireland.com/AboutUs/.
[50] This report quotes annual export sales on only €1B.
[51] http://www.ionainstitute.ie/home.php.
[52] http://www.sigma.ie/.
[53] http://www.letsys.com/.
[54] http://www.ndp.ie/docs/NDP_Homepage/1131.htm.
[55] www.eirgrid.com/media/Connected%20Wind%20Report%2020090901%20V1.pdf.
[56] www.eirgrid.com/media/Connected%20(Other%20Types%20of%20Generators)_14092009.pdf.
[57] Only proposed wind farm projects that had already secured planning permission were eligible to enter the AER V and AER VI competitions.

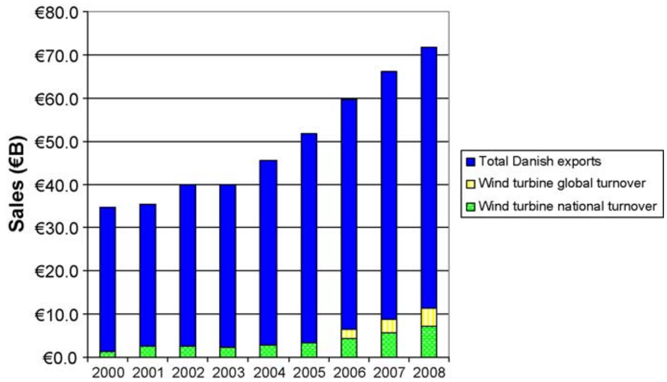

Fig. 6. Wind turbine sales in Denmark, 1996–2008. Global wind turbine sales include turnover from international facilities owned by Danish companies, data only available from 2006–2008. [81]. Danish exports extracted from http://www.indexmundi.com/g/g.aspx?c=da&v=85.

This provided wind farm developers with an alternative to the AER route to the market and resulted in 338 MW installed wind capacity by the end of 2006.

A further measure implemented to support wind farm deployment was through tax relief of corporate investment under Section 62 of the 1998 Finance Act [63]. The relief was capped for a single project at 50% of all capital expenditure (excluding lands), net of grants up to a limit of £7.5 M. Investment by a company or group of companies in more that one qualifying project was capped at £10 M per annum. This relief was extended to 2006 under Section 39 of the Finance Act 2004 and subsequently to 2011 under Section 51 of the 2007 Finance Act.

Recent initiatives have significantly addressed the early barriers to wind energy deployment. REFIT[58] replaced the AER scheme in 2005 and provides market support to wind farm projects that have secured planning permission and grid connection agreements.

The procedure for securing planning permission for wind farms has improved with a number of local authorities providing a clearer statement of suitable locations for wind farm deployment from a spatial planning perspective. This initiative seeks to address the possibility of the lapsing of planning permissions due to external approval delays. In addition, for strategic infrastructure such as major electricity transmission lines, thermal power stations and large onshore wind farms, the Planning and Development (Strategic Infrastructure) Act [69], 2006 provides a single stage consent process for approval of strategic projects. An amendment Bill to the over-arching Planning and Development Act, 2000 was published in 2009,[59] integrating the foreshore consent process for offshore wind (and other infrastructure) with the consent process under the Strategic Infrastructure Act. The Bill also allowed for extending the life of existing planning permissions for wind energy projects in certain circumstances e.g. due to difficulties in securing grid connections. Any future Irish programme for offshore renewable development will be subject to a Strategic Environmental Assessment[60] (SEA) process. The SEA for the marine renewables sector (incorporating wind, wave and tidal) is due to be completed by 2010 [70].

Regarding grid connection, the Transmission Grid Code and Distribution Code for wind energy were approved 2004, specifying the requirements for fault ride through, frequency response requirements, voltage requirements, signals, controls and communications [71]. In addition, in order to accelerate the processing of grid connection agreements, clustering of wind farm applications has developed, with €30 M made available in the National Development Plan (NDP 2000–2006)[61] to fund grid upgrades based on perceived demand for shared infrastructure, and clusters with two or more projects. This has lead to the current situation where, in addition to the 1161 MW installed, there are 1,444 MW contracted to be connected and a further 3900 MW being processed for grid connection within the 'Gate 3′ cluster [72].

Further initiatives that the Irish government carried out which supported wind energy deployment were:

- Survey on attitudes to wind energy [73].
- The wind energy map was completed in 2004.[62]
- The Wind Farm Planning Guidelines [74], specifying suitable wind farm locations, informed by the availability of the resource and the strength of the electricity networks.

3.2. Wind energy in Denmark

Denmark ranks first in the world in terms of having the largest share of domestic electricity supply from wind (23% in 2006[63]), and fifth (after Germany, Spain, the United States, and India) in terms of total domestic wind energy deployment (3136 MW) [45]. Denmark operates an electricity grid with areas such as Western Denmark integrating 41% of wind into its portfolio during January 2005 [45]. Denmark exported US$7.4B in energy technology and equipment in 2005, which was approximately 3.2% of GDP,[64] approximately 8% of total Danish exports and one-third of the total world market. The early support for wind energy by the Danish government in the 1970s created a big home market for wind turbines and gave the Danish manufacturers first mover advantages in the world market [75].

3.2.1. Policies stimulating innovation

Innovation has been a keystone in the Danish wind success model. Danish support has historically been directed towards basic research [76], unlike other governments who have tended to support wind turbine development. The knowledge acquired from the Danish publicly funded projects was available in the public domain, and that the know-how thus was available to the national wind industry. The first major initiative implemented by the Danish government in the early 1980s was the completion of a comprehensive wind atlas [77]. This research both benefited researchers in wind knowledge but also the developers in siting turbines in the most efficient locations available.

Danish researchers took a bottom-up strategy of wind turbine development—a slow, crafts-oriented, step-by-step process including incremental learning through practical experience. The smith industry and tradition of building wind turbines, started in the late 19th century, and started as private/individual experiments [75]. The strategy seemed superior to the top–down approach of science-oriented German and American researchers and manufacturers, who aimed at massive, centralized, quick and ambitious full-scale development [78].

In 1974, energy taxes were imposed, resulting in electricity prices of €0.25/kWh, which was much higher than Germany and UK prices at the time (€0.19/kWh and €0.13/kWh respectively)

[58] http://www.dcenr.gov.ie/NR/rdonlyres/67F3BEFB-FAE2-443A-A93E-93C6DEE7485F/32331/REFITclarificationsfinal2.doc.
[59] http://www.environ.ie/en/DevelopmentandHousing/PlanningDevelopment/Planning/News/MainBody,20366,en.htm.
[60] http://www.sei.ie/Renewables/Ocean_Energy/Offshore_Renewable_SEA/.
[61] http://www.ndp.ie/docs/NDP_Homepage/1131.htm.
[62] http://www.sei.ie/Renewables/Wind_Energy/Wind_Maps/.
[63] http://www.windpower.org/download/378/profilbrochure_2008.pdf.
[64] http://ec.europa.eu/economy_finance/pdf/2009/springforecasts/dk_en.pdf.

[45]. R&D for wind energy was funded through these energy taxes. It was effective method for providing financial support for public research, while spreading the costs of that research among all electricity customers [45]. Such taxes are more equitable because they are based on the amount of energy consumed but funded just by ratepayers instead of all taxpayers.

The RISO research centre was established in 1978 with a purpose to help develop wind turbines for industrial production within a period of 3 years, and if successful, carry out standard testing for the manufacturers [75]. The institute was instrumental in accumulating technology expertise in Denmark due to legislation requiring all wind turbines deployed in Denmark, that avail of the Danish investment grants, be initially tested and approved in RISO [75]. This included design of the turbine, the tower, the base and the electrical systems. RISO thus accumulated a rapid repository of technical know-how in wind energy research, and had a flow on effect to developing a manufacturing base.

Further initiatives stemming from RISO was the capacity paradigm for wind turbines stating that all components should be dimensioned twice as powerful as the traditional norm stated [75]. "This standard certification is one of the major reasons for the success of Danish wind turbines in the world market, as Danish turbines gained the reputation of being able to withstand the power of strong winds and therefore more reliable than other foreign designs".

The Danish Research Consortium for Wind Energy [79] was established in 2002 comprising of 150 researchers working with meteorology, fatigue loads, aero- and structural dynamics, grid interaction etc. Danish research institutes and wind turbine manufactures presently hold 33 patents in wind technology [80].

3.2.2. Policies stimulating manufacturing

Denmark has the highest penetration nationally of wind energy for electricity production in Europe in 2009 at 19.7% with a total of at 3 GW capacity. The Danish wind turbine manufacturers hold a world market share of approximately 40%, employing 28,400 by the end of 2008, an increase of 5000 from 2007 (Fig. 6) [81]. The wind industry is Denmark's third largest exporter [77], contributing 12% of the total export trade. Of all turbines produced in Denmark, 95% are destined for the export market. The Danish wind industry has experienced an explosive growth in the last 10 years. From turnover figures in 1996 at €0.4B, the turnover had in 2006 increased to €4.3B. This turnover only concerns production within Denmark. Including turnover from international facilities owned by Danish companies the turnover reached €6.5B in 2006. Global sales rose to €11.4B in 2008 an increase of 29% from 2007. By 2003, global offshore installations had reached 530 MW of which 492 MW were of Danish origin. Danish companies Vestas, NEG Micon and Bonus have all been among the 10 largest wind turbine manufacturers; in 2004, the two former merged and consolidated the Danish number one position in the world market, while the latter was bought by Siemens. The largest independent blade manufacturer (LM Glasfiber) is also Danish, and there are also many other leading subcontractors.

The origins of Danish Government's policy initiatives to stimulate wind turbine manufacturing began in the 1970s with the implementation of high energy taxes, resulting in high domestic electricity prices, and were kept high even after fossil fuel prices dropped in 1980s. The wind turbine manufacturing industry could thus rely on unwavering electricity prices and secure local market for their product [45]. Further incentives for industry were low taxes on electricity used for manufacturing purposes, resulting in the lowest electricity prices in Europe, around €0.05–0.06/kWh [82].

The equivalent of the Irish Development Authority (IDA) was set up in Denmark in 1982, called the Danish Council for Technology,[65] and was one of the first European government agencies setup to promote Danish manufacturing exports.

In 1985 and again in 1992, an agreement was reached between the Government and the electricity utilities, committing the utilities to install a total of 200 MW over a five-year period (and fully implemented by 1992), providing a guaranteed market for turbine production.

The most important incentive introduced to boost wind turbine manufacturing was the 30% investment subsidy introduced in 1979 [77]. The subsidy was not given to suppliers, but to individuals and cooperatives based on residence criteria. The subsidy dramatically increased local demand for turbines and enabled indigenous manufacturing to prosper.

In 1986–1987, the investment subsidy was reduced from 20% to 10% and completely removed in 1989 [77]. These abrupt changes in such a limited time, in combination with export market difficulties caused all Danish manufacturers apart from Bonus to go bankrupt or become technically insolvent. The only increase in installed capacity in the early 1990s was due to the agreement between power companies and government in December 1985 that the former should install 100 MW of wind power within the end of 1990.

Danish wind energy industries that survived the subsidy withdrawal mostly started as small speciality services companies, who then branched out into the manufacturing of wind turbines. Nordtank (now merged into NEG Micon), was originally a manufacturer of road tanks for the oil industry but decided to utilize its experience in working with steel and designed its own wind turbine [75]. The same situation occurred for Vestas – a former blacksmiths workshop – that utilized its know-how in machine production to make wind turbines for Bonus wind turbines.

In 1990, the "Danish Wind Turbine Guarantee" act was passed. This guarantee provided long-term financing of large wind projects that used Danish made wind turbines, reducing the risk of building larger projects and encouraging local manufacturing [45]. Local production created opportunities through the sales of new products, jobs, and an increased tax base, further enhancing economic growth. Manufactures used their domestic turbines as a real world laboratory to experiment, lower the cost of turbine equipment, and improve capacity factors [83].

Policy instruments to stimulate wind power and wind industry development in Denmark, such as investment and production subsidies, have been gradually removed in line with cost reductions and maturity of the industry. These policies enabled Denmark wind turbine manufacturing industry to establish itself and become a world market leader in the technology.

3.2.3. Policies stimulating deployment

Denmark has had the most successful history of deployment in Europe up till 2002, when a new government changed policy (Fig. 7). Since then, there has been virtually no national deployment, aside from the replacement of older wind turbines with new ones. In 2009, Denmark still has the highest penetration of wind energy for electricity production in Europe in 2009 at 19.7% with a total of over 3GW installed capacity.

Denmark had an early carbon abatement program of reducing CO2 emissions by 22% between 1988 and 2005 [82]. Thus, more than one-third of that target was to be met using wind energy to replace coal-fired power generation.

[65] http://en.fi.dk/councils-commissions/the-danish-council-for-technology-and-innovation.

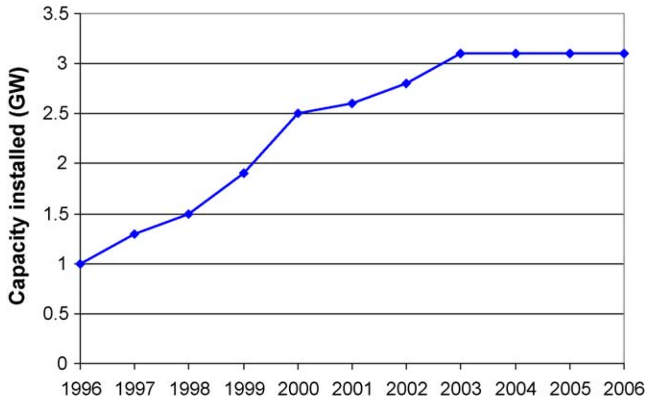

Fig. 7. History of Denmark's wind turbine installation program (GW) http://www.windpower.org/composite-1458.htm.

Considerable increase in installed capacity occurred in 1980, and the subsequent gradual increase in installed capacity and average production capacity, correlated with the 30% investment subsidy introduced in 1979 [77]. Eligibility criterion for the investment subsidy stipulated that all turbines for deployment in Denmark be tested by RISO [75].

The Danish wind energy atlas was completed early in the 1970s, funded by RISO, and enabled developers to efficiently site their turbines in the most efficient locations available [76].

In 1981, a feed-in tariff was implemented which required utilities to buy all power produced from renewable energy technologies at a rate equal to 70–85% of the consumer retail price of electricity in a given distribution area, providing assured returns for developers of wind energy projects [84].

Co-operatively owned wind turbines were exempted from tax, leading to tax expenditures in the order of DKr 70 to 90 million per year [85].

In 1990, the Danish Energy Authority provided "open and guaranteed access to the grid", i.e. shallow grid connection charges where the wind turbine owner had to bear the costs of the low-voltage transformer and connection to the nearest connection point on the 10/20 kV distribution grid and the utilities had to cover the costs for reinforcement of the 10/20 kV distribution grid where needed.

In 1992, the government levied a general carbon tax on all forms of energy, adding around €1.3/kWh of additional income for renewable energy generators. Sovacool, Lindboe, et al. [45] comment that carbon taxes did not have deleterious effects on the overall economy, and that, implemented properly, can be a useful tool for promoting cleaner energy systems.

Also in the same year, an executive order from the Minister of the Environment and Energy ordered municipalities to find suitable sites for wind turbine siting throughout the country [76]. This "prior planning" with public hearings in advance of any actual applications for siting of turbines helped the public acceptance of subsequent siting of wind turbines considerably.

In 1990, a long-term planning initiative, Energi 2000, set a goal of 10% or 1500 MW of wind power by 2005. 4000 MW offshore wind power within 2030 was later added to the target, with the aim of 50% of Danish electricity should be covered by wind power in 2030.

In 2000, an 'Executive Order' required utilities to phase in an additional 200 MW of onshore wind in 2000, followed by a request to construct two 5 MW demonstration offshore wind farms to pave the way for a final agreement on a 160 MW offshore park (implemented in 2002) [45].

From 2002, a new change in government saw a withdrawal of most of the conventional support mechanisms for wind energy installation in Denmark [77]. This led to a collapse of national wind capacity installation (Fig. 7) However, international exports continued to expand (Fig. 6), demonstrating that subsidies, if existent for a sufficient length of time (30 years in Denmark's case), can create a robust industry, which is not reliant on government support for survival.

Subsequent to 2002, new Danish wind farms were awarded the market price plus a fixed premium per kWh. All offshore parks competed on open tenders, and were based on a fixed feed-in tariff for the first 12 years. Sovacool, Lindboe, et al. [45] maintain that feed-in tariffs provide long-term certainty to renewable energy developers and investors.

In 2003, the government created the Danish Energy Authority and the "one-stop-shop" for offshore wind park planning applications, including the tendering of bids, approval of pre-investigation of sites, environmental impact assessments, construction and operation and licenses to produce electricity.

The Danish transmission and distribution system also assisted in Denmark's wind energy experience, with a preponderance of high-voltage transmission lines delivering power over smaller distances with low voltage levels. The grid is "tight" and as such, efficiency losses are very low at just 5–6%. As a result of this efficient network, Norway, Sweden, and Finland have built extensive interconnectors through Denmark, sending three times the amount of energy needed in Denmark through its wires on most days, to markets both in Denmark and the rest of Europe [45]. Legislation has also encouraged the creation of many peaking plants and storage facilities e.g. cold storage plants. The ability to channel and store such large amounts of electricity from its neighbours adds significant amounts of regulating power, helping balance wind energy at low cost. There is a significant correlation between wind power production and export to neighbouring countries. It can be argued that this export is "stored" in the Nordic hydro reservoirs to be bought back in times with no wind [45].

The development of the industry has been greatly affected by this positive encouragement from the public who has supported the national wind turbine industry almost from day one. Denmark has shown that a different model is possible, through the formation of local guilds and non-profit partnerships of wind turbine owners, who pool their capital investment in local wind turbines. In 1999, 50% of Denmark's 3200 turbines were owned jointly by 67,000 guild members [75]. Public support and investment created an environment and national market, without which the industry as a whole probably could not have survived.

In conclusion, the early support mechanisms for wind energy sources from the Danish government had mutually beneficially and compounding effects on all three industrial sectors: R&D, manufacturing and deployment, as shown in Table 8. They created a large home market for wind turbines and gave the Danish manufacturers first mover advantages in the world market.

4. Policy gaps in Irish wave energy industry

The Irish Celtic tiger experience has proven that, with the right set of policy initiatives and stimuli, thriving industry sectors in all three areas of innovation, manufacturing and deployment can be created and sustained. There is now an opportunity to harness this experience and build a comprehensive wave energy strategy that will stimulate innovation (drawing on the successes in ICT and biotech), manufacturing (drawing on successes in food, pharmaceuticals and ICT) and deployment (drawing on the success in wind energy).

This wave energy strategy can also look to the comprehensive approach adopted in Denmark that successfully stimulated innovation, manufacturing and deployment of wind energy to create an industry that became one of the world's market leaders and centres of excellence in the technology.

Table 8
Historical policies in Denmark and the interrelationships relating to R&D, manufacturing and deployment in the wind energy industry.

Policies stimulating Deployment	Policies stimulating Manufacture	Policies stimulating R&D
Carbon abatement program and Targets		
Tariffs and premiums (70% of retail rate)		
Shallow connection charges		
Carbon tax €0.01/kWh		
Compulsory construction of 200MW of capacity		
Compulsory construction of 150MW offshore wind		
Danish Energy Authority – 'one stop shop'		
High tech grid network and interconnectors allowing energy balancing		
Peaking and storage plants		
Municipalities to designate wind turbine zones		
Tax exemptions	Tax exemptions	
High retail electricity prices (energy taxes)	Low industry electricity prices	Carbon and Energy taxes (€0.25/kWh)
30% investment subsidy	Compulsory Danish made turbines in order to be eligible for investment subsidy. "Danish Wind Turbine Guarantee" (finance for Danish made turbines)	
Stable government	Stable government	Stable government
Cooperative owned projects with targeted support		
	Council for technology promoting exports	
		Bottom up design
		RISO national lab All turbine designs must be approved by RISO Danish made turbines to have double power rating
Comprehensive wind atlas		Comprehensive wind atlas

The strategy can build on existing policies in place for wave energy in Ireland that are already quite comprehensive in comparison to other international initiatives. The focus to date however has been on innovation and deployment of wave energy and the scale of investment and support is not aligned with the significantly greater scale of ambition. In addition the focus on a wave energy manufacturing sector has been largely ignored.

The following sections list measures which could be taken to address the policy gaps and build a wave energy strategy in Ireland that stimulates innovation, manufacturing and deployment. A summary of the mutual synergies and flow-on benefits are presented in Table 9.

4.1. Innovation

4.1.1. Policies stemming from Irish Celtic Tiger experience

The following are the policy supports that could be targeted at wave energy:

- Since 2000, there has been an enormous change of focus and support to R&D research in Ireland, with a total €2500 M devoted in 2008, representing approx 1.5% of GDP. Of that sum only €8.2 M was spent on renewable energy research of which wave energy received €3.3 M (i.e. 0.13% of R&D expenditure). If Ireland is to deliver on its goal, the total national budget for R&D needs to approach that of the USA, i.e. 3%, and a much larger proportion of that funding need to be allocated to wave energy. If the USA level of research expenditure was achieve in 2008, and 10% of R&D funding was allocated to wave energy, this would have meant a budget of €500 M rather than €3.3 M.
- Tax credit for R&D is presently 25%, and has been very successful in increasing R&D in the country. A larger specific tax relief for wave energy research of 30–40% would provide a significant incentive for more private funded research in the area.
- A Wave Energy Competence Centre could be established, building on the work of the Programs of Advanced Technology

Table 9
Current and suggested policies to foster Irish avenger wave energy innovation, manufacturing and deployment industries, showing mutual synergies and flow-on benefits.

Irish wave energy policies already in place or planned	**Policies benefitting R&D**	**Policies benefitting Manufacture**	**Policies benefitting Developer + Deployment**
	4 stage strategy OEDU		
	FIT		FIT
	Prototype funding		
	Research funding (Parsons funds)		
	Test sites		
			Targets
			Grid upgrade (planned)
			One stop shop (planned)
			SEA (planned)
Suggested policies	**Policies benefitting R&D**	**Policies benefitting Manufacture**	**Policies benefitting Developer + Deployment**
Irish Celtic Tiger and wind energy lessons	Increase R&D to 3% GCP and Wave energy R&D to 10% R&D budget	Lower corporate tax	50% tax relief corporate investment
	Tax credit for R&D	IDA interest in wave energy FDI	Strategic Infrastructure alteration
	Wave Energy Competence Centre		Grid 25 implementation
			Transmission code
			Planning permission, foreshore licence and grid connection coordination
			Spatial planning and zoning for marine energy clusters
	DETE liaison	IDA and EI liaison	DCENR liaison
Danish wind energy experience lessons	RISO model + compulsory testing of international devices deployed in Ireland	Production grants and tax incentives for Irish made WEC + long term financing	Investments grants and tax incentives for Irish made turbines + long term financing
	High redundancy requirement for devices		Compulsory construction of 200MW wave farm
			Expanded Wave atlas
			Designation of sea zones
			Shallow connection charges for distribution
			Interconnectors
		Low industry electricity prices	High retail electricity prices
	Carbon and energy taxes	Carbon and energy taxes	Carbon and energy taxes
			Cooperative owned projects with support
	Staple government	Staple government	Staple government

(PAT), developing an industry lead and part fund wave energy research and development programme.

4.1.2. Policies stemming from Danish wind energy experience

Policy initiatives from the Danish experience that are present absent from Irish policy are:

- Apply to Ireland's HMRC some of the policy elements that were in place for RISO, for example a mandate stipulating that all wave energy devices receiving Irish subsidies must have their designs tested by the centre. This would substantially add to the centres' bank of expertise, building capacity and benefitting current public research. This policy would also have a flow on affect to the manufacturing sector which would benefit from skilled expertise accrued.
- Introduce a 100% redundancy[66] rating requirement for all Irish designed wave energy devices, similar to that stipulated for Danish wind turbine devices. This policy would directly impact the manufacturing industry, and would ultimately elevate the reputation of Irish designed devices.
- Allocate a proportion of the budget to the most vulnerable stage of device development, i.e. the stage between prototype completion and pre-commercial stage (sometimes referred to as the "valley of death").
- Consider allocated a portion of the revenues gathered from carbon taxes to part fund the R&D budget.

Further initiatives that Ireland could implement are:

- Department of Enterprise, Trade and Employment (DETE), to liaise with other Government departments to coordinate a cohesive plan and strategy for all aspects of wave energy development.
- Development of national standards for wave energy devices, to act as a starting point for international standards.

4.2. Manufacturing

4.2.1. Policies stemming from Irish Celtic Tiger experience

Ireland's Celtic Tiger experience was significantly stimulated due to the low corporate tax rate of 12.5% introduced in the 1980s. In 2009, a rate of 0% was extended to new companies for the first 3 years of their operation. The following is suggested to assist wave energy companies:

- Introduce a corporate tax rate of 3–5% from year 4 to year 10, in addition to the 0% tax rate for the first 3 years. This would allow wave energy manufacturing companies to firmly establish themselves in the market. Belgium and Bulgaria have much lower corporate rates that Ireland at −3.4% and 4%, respectively [86]. In 2009, the first renewable energy manufacturing company opened operations in Ireland. This was a small scale wind turbine manufacturing operation in Galway, Ireland, with the promise of 250 jobs in full production (Open Hydro tidal turbines has not started commercial production yet).
- IDA could include a specific targeted effort in its remit to encourage FDI and MNC to set up wave energy manufacturing facilities in Ireland. This policy is currently been considered by the IDA at present.[67] Historically though, there has been little success in nurturing an MNC based renewable energy manufacturing sector to date in Ireland. Moreover, the top-10 wind turbine manufactures in the world control 97% of the market [87], and base the majority of their operations their native countries.

4.2.2. Policies stemming from Danish wind energy experience

Analysis of the Danish wind energy experience demonstrated that there were very few direct manufacturing policies. The manufacturing sector responded to positive conditions created in the R&D sector as well as in deployment. Additional policies from the Danish experience that would directly benefit Irish wave energy manufacturing would be:

- Investment subsidies and production subsidies which require eligible developers to manufacture devices in Ireland. These could be reduced in time to stimulate competitiveness in the industry.
- Long term financing for wave energy manufacturing projects.
- Low industry rate electricity prices to assist in reduction of costs. Ireland had the forth highest electricity prices for industry in Europe in 2008.[68]
- Coordination of policy initiatives is required between the Department of Industry and Trade promoting manufacturing, with other departments responsible for innovation and deployment.

4.3. Deployment

4.3.1. Policies stemming from Irish wind energy experience

A Renewable Energy Strategy Group was formed in 1999 with a specific remit to develop a wind energy deployment strategy for Ireland. The Group considered market support mechanisms, planning considerations and integration of wind energy into the electricity networks. This provided a sound foundation on which successful policies were developed, in a large part due to the engagement that took place within the Group on the challenges facing wind energy.

- The Department of Communications, Energy and Natural Resources should establish a Wave Energy Strategy Group should be formed with a tight brief to develop a strategy to address the challenges facing delivery of the specific 500 MW target by 2020. The Group should engage with the researchers and with the emerging wave energy industry as well as the planning authorities, State bodies and the electricity supply industry.
- DEHLG to complete a spatial planning study investigating zoned areas for development and clustering of marine energy developments.
- Local authorities should identify areas that are suitable or not suitable form a spatial planning perspective for wave energy deployment.
- The electricity system operators should include specific guidelines within the grid code for wave energy devices as is currently the case for wind energy devices.
- The transmission network expansion plan, Grid 25, needs to be elaborated and implemented in order for the grid infrastructure to be ready and available by 2020 for at least 500 MW of ocean energy in addition to the other renewable energy plant required to deliver 40% renewable penetration.
- The Planning & Development (Strategic Infrastructure) Act 2006 should be extended to include offshore wave energy but this will

[66] Power rating of a device is a guideline set by the manufacturer as a maximum power to be used with that device. In order to attain a 100% redundancy for example, a 1 MW rated device would need to able to accommodate 2MW of peak power.

[67] Personal communication Ray Bowe (IDA) at the Marine Renewable Association (MRIA) meeting Oct 2009.

[68] http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-09-025/EN/KS-QA-09-025-EN.pdf.

require Involvement of the Marine Institute and other members of the Marine Licence Vetting Committee[69] in the decision making process.
- All three requirements of planning permission, foreshore licence and grid connection must be obtained before application for a feed in tariff can be made.
- The extension of the 50% tax relief for corporate investment in marine renewables, similar to onshore wind.
- Increase of the FIT from €0.22/kWh to €0.30/kWh or perhaps €0.40/kWh, in line with the PV FIT in Germany [3].

4.3.2. Policies stemming from Danish wind energy experience

Successful Danish wind energy policies which could assist the Irish wave energy industry are as follows:

- An investment subsidy comparable to the 30% subsidy provided by Denmark. The policy would be enhanced by a stipulation requiring applicants manufacture their devices in Ireland in order to be eligible for the grant. The policy thus would not only benefit developers but would also have a direct flow on effect of stimulating the manufacturing industry. Variation of government policy over time can lead to instability in the market, as demonstrated in Denmark, where termination of government support and subsidies in 2002 led to a collapse of national wind capacity installation. However, international exports of Danish made turbines continued to expand, demonstrating that subsidies if existent for a sufficient length of time (30 years in Denmark's case), can create a robust industry, which is not reliant on government support for survival.
- Executive order or mandate, decreeing utility built wave farm construction projects of the size of 100 to 200 MW. These projects could require turbines to be manufactured in Ireland if they were to avail of the investment grant (flow on benefit the manufacturing sector). The mandate would help guarantee reaching government targets for installation, as well as assist manufactures with a guaranteed market.
- In order to reduce planning permit problems and delays, a government mandate decreeing compulsory designation by local authorities of sea area leases or zones for development.
- Multiple interconnectors with both the UK and mainland Europe to provide export networks for the excess energy as well base load capacity to support high penetration of renewables. Two companies at present are competing for the €110 M EU grant, Eirgrid and Imera.[70] The first cable is promised to be in place by 2012.
- In order to enable high penetration of wave energy into the grid system, more peaking plants as well storage plants will need to be planned, e.g. compressed air, pumped hydro, cooling plants, etc.
- A GIS site selection tool, providing premium locations sites for wave energy deployment in Ireland, including wave energy data, bathymetry, best port locations, nature reserves, etc.
- Greater liaison and cooperation with regards unified policy and strategy between government department overseeing the deployment sector (Department of Communications, Energy and Natural Resources (DCENR)) and other departments responsible for innovation and manufacturing.

[69] Previously the Marine Licence Vetting Committee provided technical, scientific and engineering advice to the Minister in relation to the environmental impacts that may arise from proposed developments and made recommendations regarding appropriate conditions in the event of approval. The Committee comprised representation from various Government Department and State agencies including the Marine Institute and National Parks and Wildlife Service.

[70] http://www.examiner.ie/story/Business/idmhkfeykf/rss2/.

5. Conclusion

This paper has presented the current state of wave energy policy both in Ireland and in Europe, as well as presenting the successful cases of the Irish Celtic tiger, the Irish and Danish wind energy experiences. Irish wave energy policy was then examined to assess whether current policy, which is seen to be one of the most progressive in the world, could be improved upon. The purpose of this analysis stemmed from the ambition of the Irish Government not being matched by activity and stimulus. It does not provide a full cost benefit analysis but rather points to what policy mechanisms can be employed if Ireland wishes to become a world leader for research, development and deployment of ocean energy technologies.

Irish government initiatives in all three core areas of innovation, manufacturing and deployment were shown in the paper to be very successful in creating a positive environment for success, resulting in the Celtic Tiger experience. World class industries were established and continue to flourish in IT, bio-pharmaceuticals and food industry. The experience demonstrated that the Irish government has the capacity to successfully develop policy necessary to stimulate an industry once it sets out to do so. The Irish wind energy experience has shown that policies can be put in place that successfully deploy renewable energy plants in a relatively small timeframe. Government incentives and policies started only a decade ago, increased wind penetration from zero to one of the highest in Europe. However, the targets for wind energy were for deployment only and Irish R&D and manufacturing in wind energy did not evolve as a result.

Denmark, on the other hand, has been shown to be an excellent example of how prudent government policies can establish a successful wind energy industry spanning all three industry sectors of innovation, manufacturing and deployment. The Danish wind energy industry in its early years had no market and a weakly described technology. Lessons from Danish wind energy experience showed that the policy provision at an early stage created a relatively large user group from the beginning. This, greatly stimulated learning by using and learning by interacting between the turbine users and the turbine producers. The RISO institute was the cornerstone of this interaction, providing a repository of knowledge excellence in R&D and innovation. Denmark's real success lay on foundation of mutually beneficial policies and strategies which cross benefited along the sectors. A major boon to the wind energy industry in Denmark was the stability of Danish energy policy for a long enough period to ensure successful establishment of the manufacturing sector, leading to becoming the world's largest international exporter of turbines. Subsequent changes in government policy had no deleterious effect on this manufacturing sector due to its strong international presence. It could be argued that this Danish example of providing support in the beginning and gradual withdrawal of support as the industry establishes could be a template for other governments trying to establish a new industry sector, creating a resilient industry that will survive in international competition.

Analysis of the wave energy policy in Ireland revealed that the basic strategy is correct, but the extent needs to be greatly expanded and the delivery needs to be guaranteed. The ratification of the €0.22/kWh FIT was a welcome initiative from the government, and can be viewed as a solid commitment by to positively support the industry. However, FIT are virtual until they are drawn upon, which in the international wave energy context could be many years away. Thus the FIT initiative can be possibly misleading, funding a future scenario while present policies and funding are lacking or in need of implementation.

Seven main policy initiatives were identified which could ensure the successful establishment of a full wave energy industry in Ireland:

- The Department of Communications, Energy and Natural Resources should establish a Wave Energy Strategy Group should be formed with a tight brief to develop a strategy to address the challenges facing delivery of the specific 500 MW target by 2020.
- Ireland needs to significantly increase the annual wave energy R&D budgets, including critical financing for the full-scale demonstration stage of innovation i.e. the stage between successful prototype demonstration and the pre-commercialisation stage. The current annual budget of €3.3 M needs to increase approx one hundred fold over the next 10 years.
- Ireland's electricity system operators should include specific guidelines within the grid code for wave energy devices as is currently the case for wind energy devices.
- Establish a capital grant investment subsidy comparable to the 30% subsidy provided in the early stages of wind energy deployment in Denmark. The policy would be enhanced by a stipulation requiring applicants manufacture their devices in Ireland in order to be eligible for the grant.
- Introduce a reduced corporate tax rate of 3–5% from year 4 to year 10, in addition to the 0% tax rate for the first 3 years. This would allow wave energy manufacturing companies to firmly establish themselves in the market.
- Fast tracking appropriate policy in the various government departments for planning permission, foreshore licences and suitable grid connection/infrastructure.
- Increase the current proposed FIT from €0.22/kWh to €0.30/kWh or €0.40/kWh, similar to that provided for PV in Germany.
- Standards for wave energy devices in conjunction with other EU countries.

Finally, a stable government is crucial for long term development of policy initiatives necessary to stimulate and promote the evolution of the wave energy industry, as was seen from the Danish experience. Liaison between all three relevant government departments responsible for innovation, manufacturing and development/deployment (DETE, IDA/EI and DCERN) are essential to coordinate a policy framework for simultaneous development of the all three wave energy sectors.

In conclusion, Ireland has the capacity and experience to successfully nurture and develop a wave energy industry. The great challenge will be for the government to identify the right balance of policies and incentives to sustainably nurture all three sectors of the wave energy industry.

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